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THE EFFECT OF DRYING CONDITIONS
ON
THE PROPERTIES OF SET PLASTER OF PARIS

BY

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THESIS

FOR THE

DEGREE OF BACHELOR OF SCIENCE

IN

CERAMICS

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

1927

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I - INTRODUCTION

A - Object of Study.

The purpose of this investigation was to determine the effect of drying conditions, as regards temperature and relative humidity, on the ultimate strength developed by pottery plaster in setting; and to determine the effect upon strength of alternate saturation with water or electrolyte and drying out.

B - Reasons for Work.

Interest developed in this work as a result of the fact that plant operators are beginning to look for information concerning the proper preparation, treatment, and care of plaster molds. It has been known for a long time that molds are sometimes injured by being dried in dryers that are maintained at too high a temperature; but it has not been known just how badly they were "burned" or the temperature at which "burning" begins. Mold makers know that their molds are weakened by their contact with water and electrolyte solutions; but they have not known how rapidly they are weakened.

In modern plants of today the conditions in plaster shop and dryer vary from plant to plant, and from day to day. This is due largely to the fact that slight scientific work has been done along this line. Some plant operators are very careful and dry their molds in dryers only slightly above room temperature. Others believe plaster will stand considerable temperature and dry their molds over steam pipes. The need of experimental work is easily seen and it was with this in view that the investigation was undertaken.

C - Previous Work.

Very little work has been done along this line of research. The only published* data was from the laboratory of the United States Gypsum Company. In this article it is stated with respect to drying temperature that "The ordinary room temperature, 70 degrees Fahrenheit is the safest. Higher temperatures up to 145 degrees Fahrenheit may be used in drying, provided that great care is exercised to see that the molds are removed from these temperatures as soon as they are dry. There is no danger of the molds being burned so long as there is an excess of water in them, but as soon as this is dried out any temperature exceeding 120 degrees Fahrenheit will cause combined water to leave the molds, resulting in their being burnt."[1]

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[1] Ceramic Industry, Pages 216-222, March 1925 : Fundamental Factors in the Use of Pottery Plaster. United States Gypsum Company

II - METHODS OF STUDY

A - General Methods Used.

In order to have fairly uniform plaster from which to make all the test pieces, five bags of Ivory pottery plaster purchased in the open market from the Illinois China Company were reserved for this work.

The test pieces for all tests were prepared in the same manner, the difference in work being only in the treatment of specimens after molding and before testing for strength.

Since a good cross-breaking machine, shown in the accompanying photograph, was available, it was decided to use cross-breaking strength tests instead of crushing strength or tensile strength tests.

In the making of the test pieces different proportions of water and plaster were used until a good mix was found that gave good strength and sufficient time for molding. This mixture was 70 parts water to 100 parts plaster. It was found that 2400 c.c. of water and 3000 grams of plaster gave about the right sized batch for filling the molds used.

Three steel molds open at top and bottom with inside dimensions 1" x 1" x 42" were used for casting the bars of plaster which were later to be sawed into 6" test pieces. The molds were placed on smooth soapstone which acted as the bottom.

In making each set of test pieces the water was measured into galvanized iron bucket and the weighed amount of plaster sifted into the water through the fingers. After all the

plaster had sunk beneath the surface of the water, it was allowed to blend for three minutes after which it was mixed for five minutes using a bucket stir. At the end of this time, the plaster was immediately poured into the molds which had previously been given a thin coating of light oil. When the plaster had begun to set, it was smoothed off with a clean spatula. The bars were left in the molds until the surface of the plaster was hard to scratch with the finger nail, about one-half hour. The steel walls, which had been held together by screw clamps, were then removed and the bars were sawed into six-inch test pieces giving 21 pieces altogether. All apparatus used was kept clean of set plaster, oil, and dust.

Sets of test pieces were subjected to various treatments in drying prior to testing for strength. The conditions of temperature, humidity, and soaking treatments are described below.

The testing for strength was done in a standard cross-breaking machine before mentioned. Since the weight applied by the machine was not sufficient to break the pieces, a five-hundred gram weight was hung on the end of the horizontal beam. This made it necessary to calibrate the machine over again, because the formula given with the machine no longer applied.

The curve, Figure I, obtained for modulus of rupture reads directly, so that the reading on the vertical bar for the breaking point of each test piece may be converted directly into modulus of rupture.

B - Materials Used.

The materials used in the investigation were:

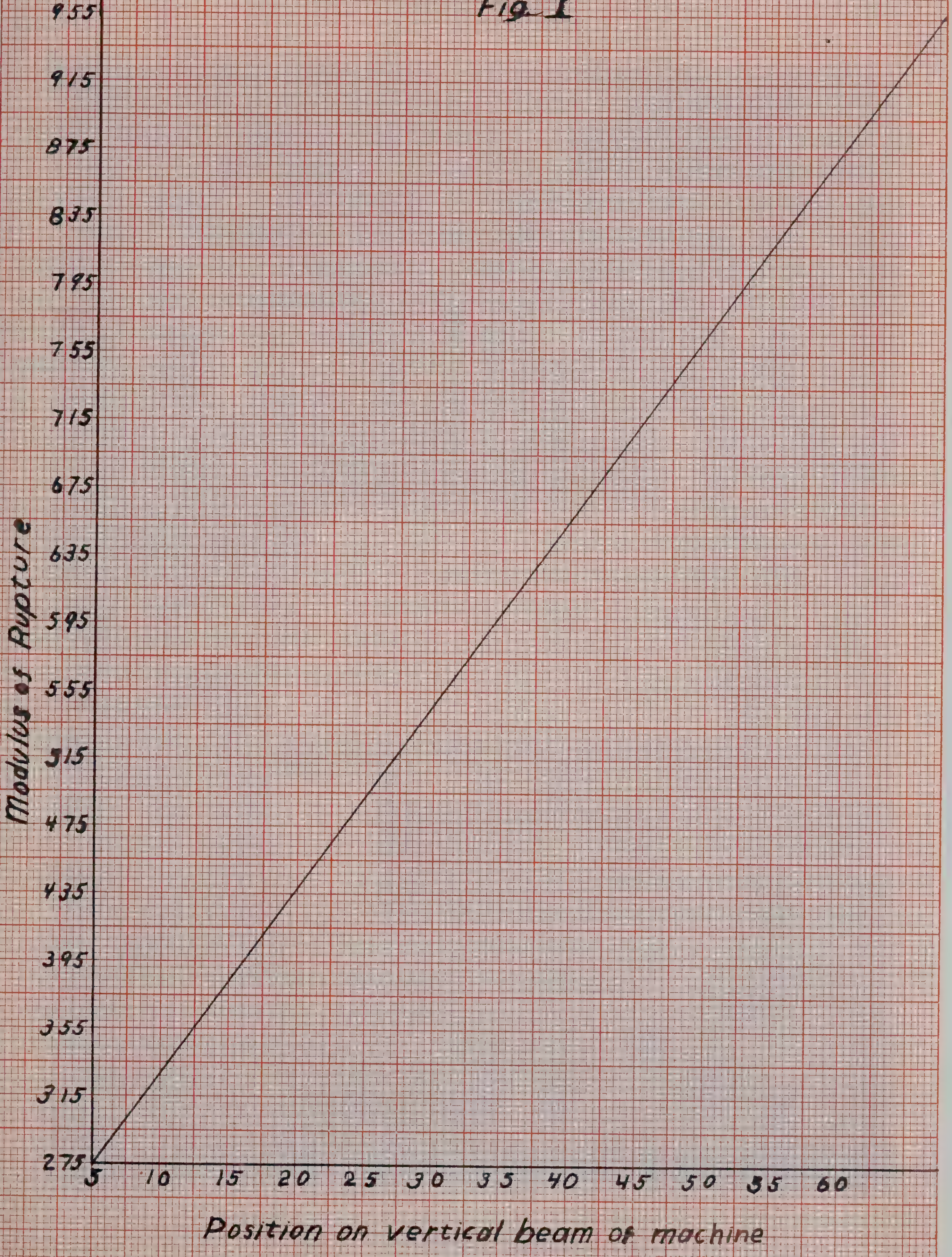
(1) Ivory pottery plaster obtained in open market from the Illinois China Company.

(2) Tap water.

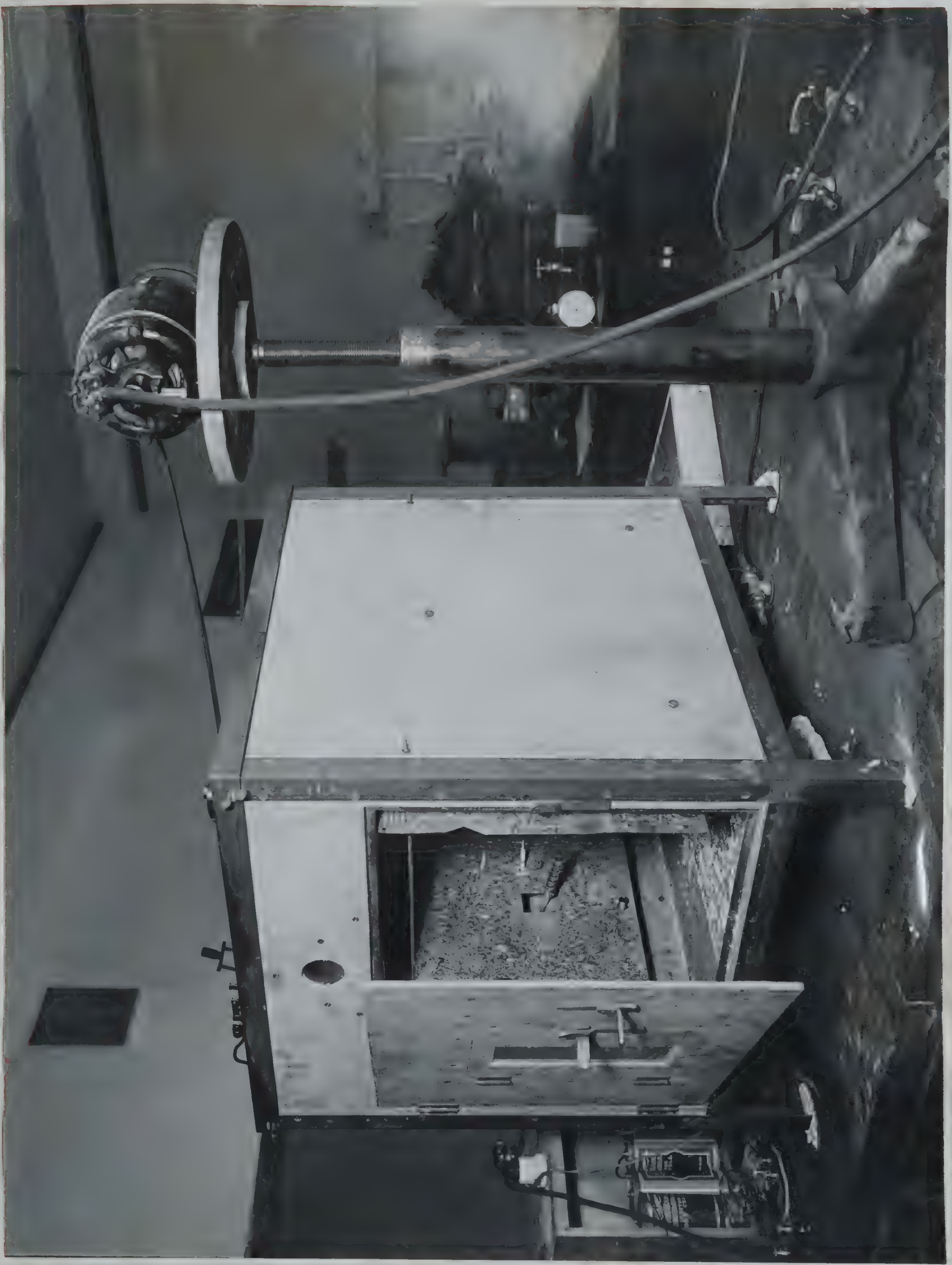
(3) C.P. Sodium carbonate.

(4) Stock sodium silicate (water glass).

Fig. I


Modulus of Rupture
955
915
875
835
795
755
715
675
635
595
555
515
475
435
395
355
315
275
5
10
15
20
25
30
35
40
45
50
55
60
Position on vertical beam of machine

DRYER



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ASSEMBLY DRAWING
CROSS BREAKING MACHINE

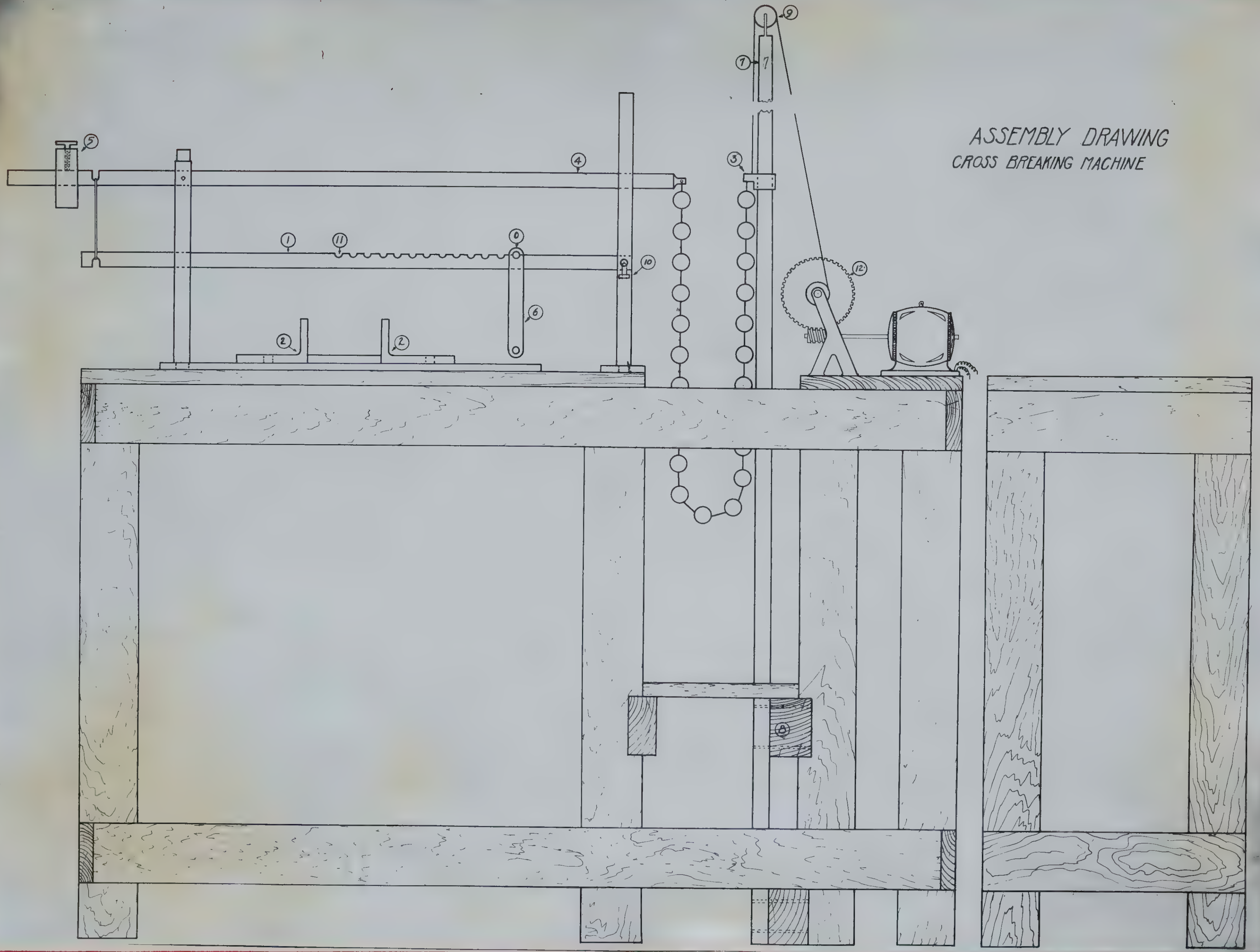

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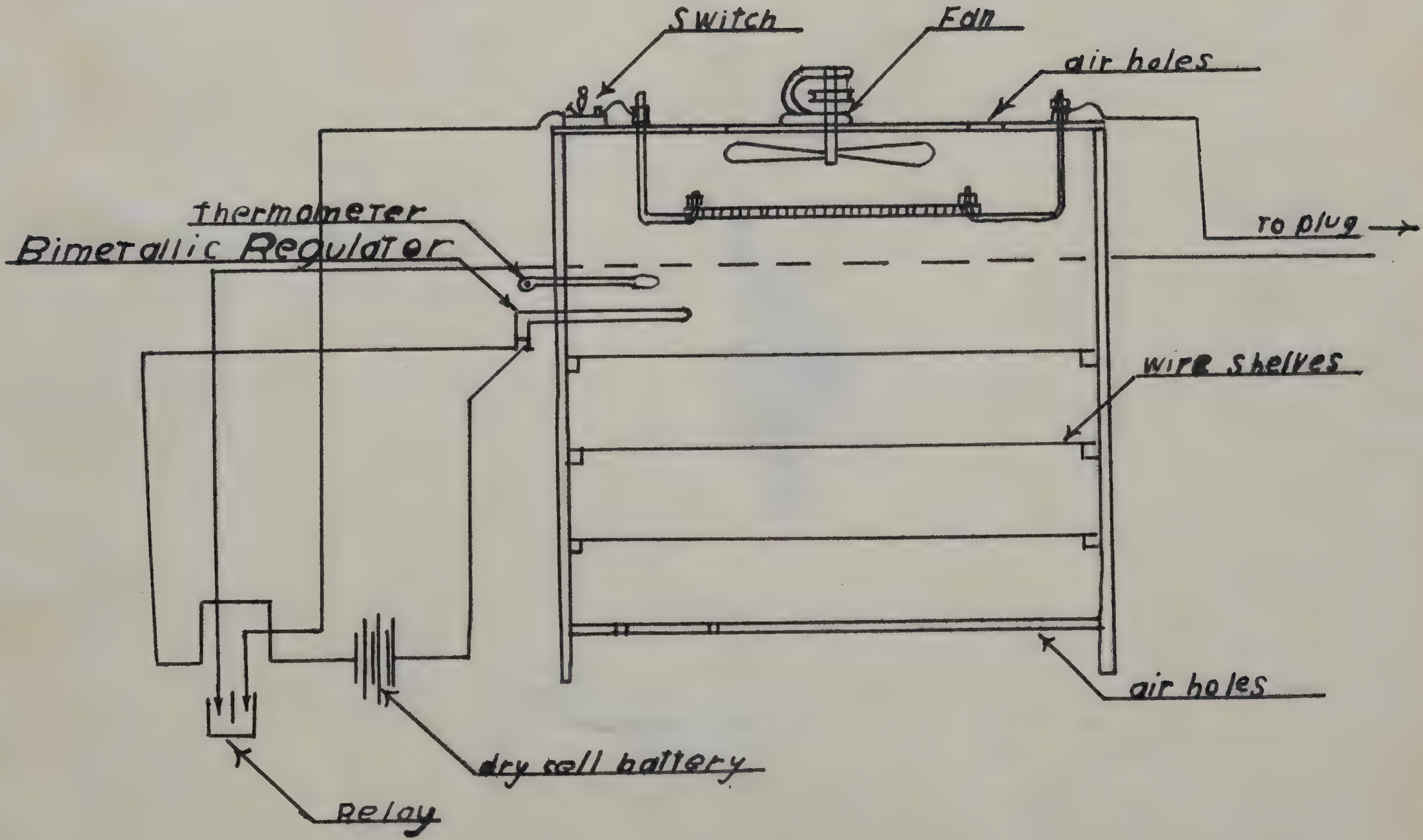
Fig. II
Vertical cross section of Dryer



III - EFFECT OF DRYING TEMPERATURE ON STRENGTH OF SET PLASTER

A - Method.

To determine the effect of drying temperature on the strength of set plaster, tests were made at the following temperatures: forty-five, sixty, sixty-five, seventy, eighty-five, and ninety-five degrees Centigrade. For each test one set of test pieces was made up in exactly the same manner as described above. The bars were allowed to set for one hour and then were placed on the racks in the dryer. A constant temperature was maintained in the dryer for the respective tests. Each set of test pieces was left in the dryer two days to allow time not only for drying, but also for partial dehydration. The bars were then removed, allowed to cool, and broken immediately in the cross-breaking machine.

B - Results.

The average modulus of rupture for each test is plotted in Figure II. According to this curve there is no decrease in strength due to drying at temperatures up to sixty-five degrees Centigrade. Above that point the strength falls off sharply, proving that dehydration of the $CaSO_4 \cdot 2H_2O$ has taken place appreciably.

As a result we may state that in the drying of plaster molds the highest temperature that may be used without "burning" them is sixty-five degrees Centigrade. Since a slightly higher temperature will dehydrate the plaster, reducing the strength greatly and materially shortening the length of life of the mold, the average temperature maintained in the dryer should never be

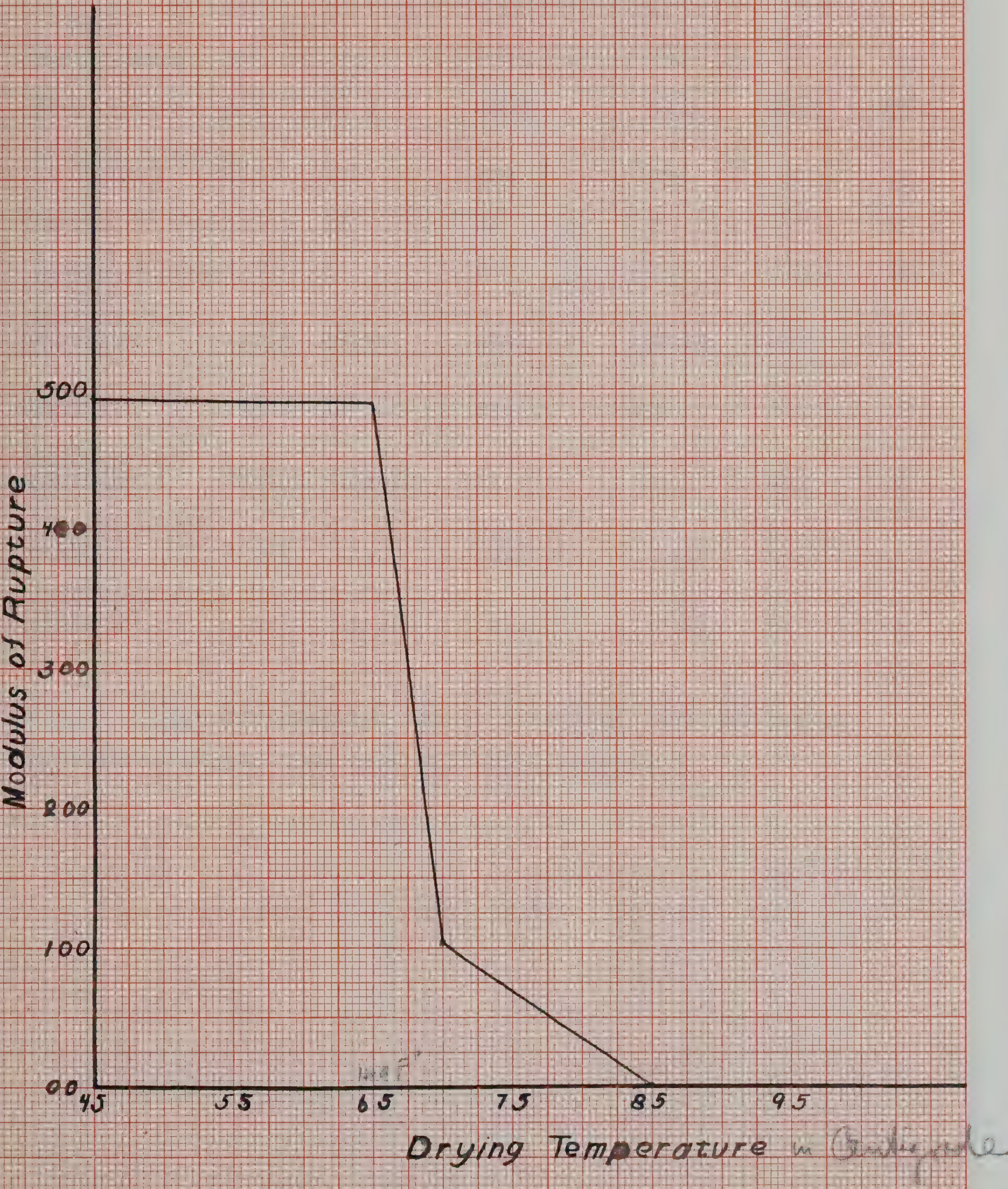
above about fifty degrees Centigrade, one hundred twenty-two degrees Fahrenheit. This allows for a fifteen degree variation in temperature in the different parts of the dryer.

C - Application of Results in Plant Practice.

Since the temperature of dehydration is so much lower than that of steam pipes, one hundred degrees Centigrade, molds should never be placed near steam pipes.

Some plants that are now drying their molds at temperatures higher than this may reduce the temperature to the above point or lower and more than overcome the decrease in drying rate by the use of forced circulation. The rate of drying is determined by the rate of air movement, the relative humidity, and the rate of diffusion of moisture from the inside to the outside of the pieces. Plaster of Paris is so porous that at least seventy percent of the drying is as from a free liquid surface. This makes the rate of drying of plaster dependent upon the rate of air movement, and relative humidity. In the ordinary dryer, however, the air movement is very slow. Although the high temperature used increases the vapor pressure in the mold, the evaporation into dead air rapidly raises the vapor pressure of the moisture in the air near to that of the moisture in the mold. This fact slows down the rate of drying greatly. The temperature can be cut to fifty degrees Centigrade and by installing a forced air system the rate of drying can be made more rapid than at the higher temperature, because of the continual change of air.

Fig. NO. II


Modulus of Rupture
500
400
300
200
100
00
149 F
45
55
65
75
85
95
Drying Temperature in Centigrade

Data For Figure II

Maximum Drying Temperature

Test Number	I	II	III	IV	V	VI
Temperature	45° C	60° C	65° C	70° C	85° C	95° C
Average modulus of rupture	492	493	491	104	0	0
Number of bars	19	17	15	19	17	20
Number rejected	0	1	0	0	0	0
Average bar position	27.2	27.26	27.1	12.51	--	--
Maximum bar position	33	39	37	16	--	--
Minimum bar position	22.25	11.625	21	10	--	--
Deviation of maximum	5.8	11.74	9.9	3.49	--	--
Deviation of minimum	4.95	15.635	6.1	2.51	--	--

The bar position may be converted into modulus of rupture by taking them from the curve, Figure I.

IV. - THE EFFECT OF STORAGE IN A SATURATED ATMOSPHERE ON THE STRENGTH OF PLASTER

A - Method.

Nine sets of test pieces, twenty-one pieces each, were made in exactly the same manner as that described in Part II; one set being placed in the dryer, dried at forty-five degrees Centigrade for twelve hours and then broken; while the other sets were placed in jars immediately after removing from molds and kept in a moist or saturated atmosphere. The jars were maintained at one hundred percent relative humidity by putting water in the bottom and placing the pieces on a brick to keep them up out of the water. A pan of water was set on top of the stack of test pieces and the jar was covered with a plaster of Paris lid. The pan of water was placed in the top of the jar to prevent the drying out of the test pieces by gravity.

At the end of nine hours one set of test pieces was taken out of the jar, placed in the dryer and dried at forty-five degrees Centigrade for twelve hours. After drying, the bars were cooled and broken immediately in the cross-breaking machine. Similarly, sets of test pieces were removed from the jars, dried and broken at the ends of one, two, four, six, seven, eight, and thirteen days.

B - Results.

From Figure III it will be seen that the plaster is practically set at the end of one day but gains some strength the following day. Although plaster appears to be thoroughly

set at the end of one hour, the hydration process is not complete and if the piece is placed in the dryer at that time the ultimate strength is about twenty percent less than it would be if left in a saturated atmosphere for two days. After two days the strength remains constant showing that the hydration is complete.

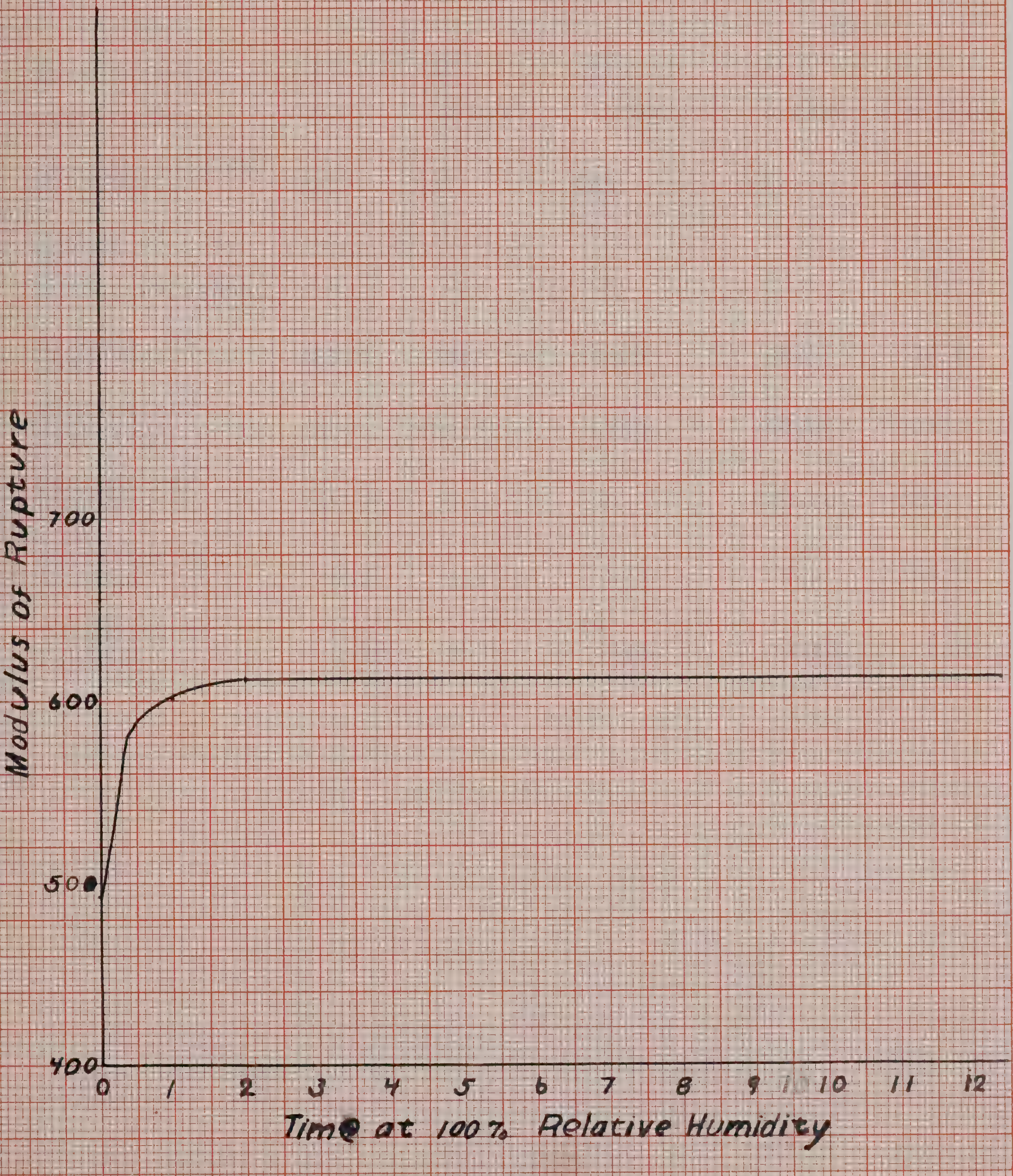
To determine whether or not test pieces which had been dried would take up moisture from saturated air and further hydrate, two sets of test pieces were made up and placed in the dryer at the end of one hour, then dried for twelve hours at forty-five degrees Centigrade. When dry, one set was placed in a dessicator having concentrated sulfuric acid in the bottom while the other was placed in a jar with the atmosphere at one hundred percent relative humidity. At the end of three days both sets were placed in the dryer, dried at forty-five degrees Centigrade for twelve hours, cooled and broken. The results show that no strength is gained by the humidity treatment given in this manner. The placing of the bars in the jar containing moist air was for the purpose of preventing the moisture held in the plaster from being dried out until the hydration was completed.

C - Application of Results to Plant Operations.

Plants may apply the above principle by leaving their newly made molds in a damp room for two days before drying them out for use. This method will increase their strength about 20% and will undoubtedly make the molds last longer. As soon as the mold is set it should be moved from the plaster shop to a damp closet and left for two days. If the mold is allowed to dry out before being placed in the damp atmosphere, no increase in strength

will result. This increase of twenty percent in strength resulting from storage in a damp atmosphere should lengthen the life of the molds at least one month by cutting down the breakage, etc. This will more than pay for the use of one room for the damp closet.

Fig. No. III


Modulus of Rupture
700
600
500
400
0
1
2
3
4
5
6
7
8
9
10
11
12
Time at 100% Relative Humidity

Data For Figure III

The Effect of Storage in a Saturated Atmosphere

Test Number	I	II	III	IV	V
Time in jar	0	9 hrs.	1 day	2 days	4 days
Average modulus of rupture	490	581	602	616	612
Number of bars	19	15	18	18	18
Number rejected	0	0	0	0	0
Average bar position	27.2	33.3	34.8	35.7	35.5
Maximum bar position	33	37.5	37.5	45.5	51
Minimum bar position	22.25	30.6	30	30.25	30
Deviation of maximum	5.8	4.2	2.7	9.8	15.5
Deviation of minimum	4.95	2.7	4.8	5.45	5.5

Test Number	VI	VII	VIII	IX
Time in jar	6 days	7 days	8 days	18 days
Average modulus of rupture	595	630	606	637
Number of bars	19	19	19	20
Number rejected	2	0	0	1
Average bar position	34.3	36.8	35.1	37.8
Maximum bar position	41.37	46	41.75	54
Minimum bar position	23.5	30	27	26
Deviation of maximum	7.07	9.2	6.65	16.2
Deviation of minimum	10.8	6.8	8.1	11.8

V - THE INFLUENCE OF REPEATED SOAKINGS IN WATER AND ELECTROLYTE SOLUTION UPON THE STRENGTH OF SET PLASTER

A - Method.

Four sets of test pieces were made up in the manner described above and placed in the dryer at forty-five degrees Centigrade. When the bars were dry, they were removed from the dryer, one set was cooled and broken, while the other three sets were placed in a shallow pan into which had been placed a five-tenths percent solution of sodium carbonate and sodium silicate used in equal amounts by weight. The solution was just deep enough to leave the tops of the test pieces out. This permitted the escape of the air and the filling of all pores by capillary attraction. At the end of three hours the test pieces were placed in jars, maintained at one hundred percent relative humidity for the rest of the day. The next day they were dried out, one set was broken in the cross-breaking machine, and the other sets were placed in a new solution of sodium carbonate and sodium silicate of the previous concentration, left for three hours and the entire process repeated.

Sets of test pieces were broken after zero, one, three, and four periods of soaking and drying. The results were plotted in Figure III.

Four more sets of test pieces were made up and treated in exactly the same manner using water instead of solution for the soakings. Tap water was used and was changed for each soaking. Sets of pieces were broken at the ends of one, three, seven, and eight, three-hour soaking periods. The results are shown in FigureIII

B - Results.

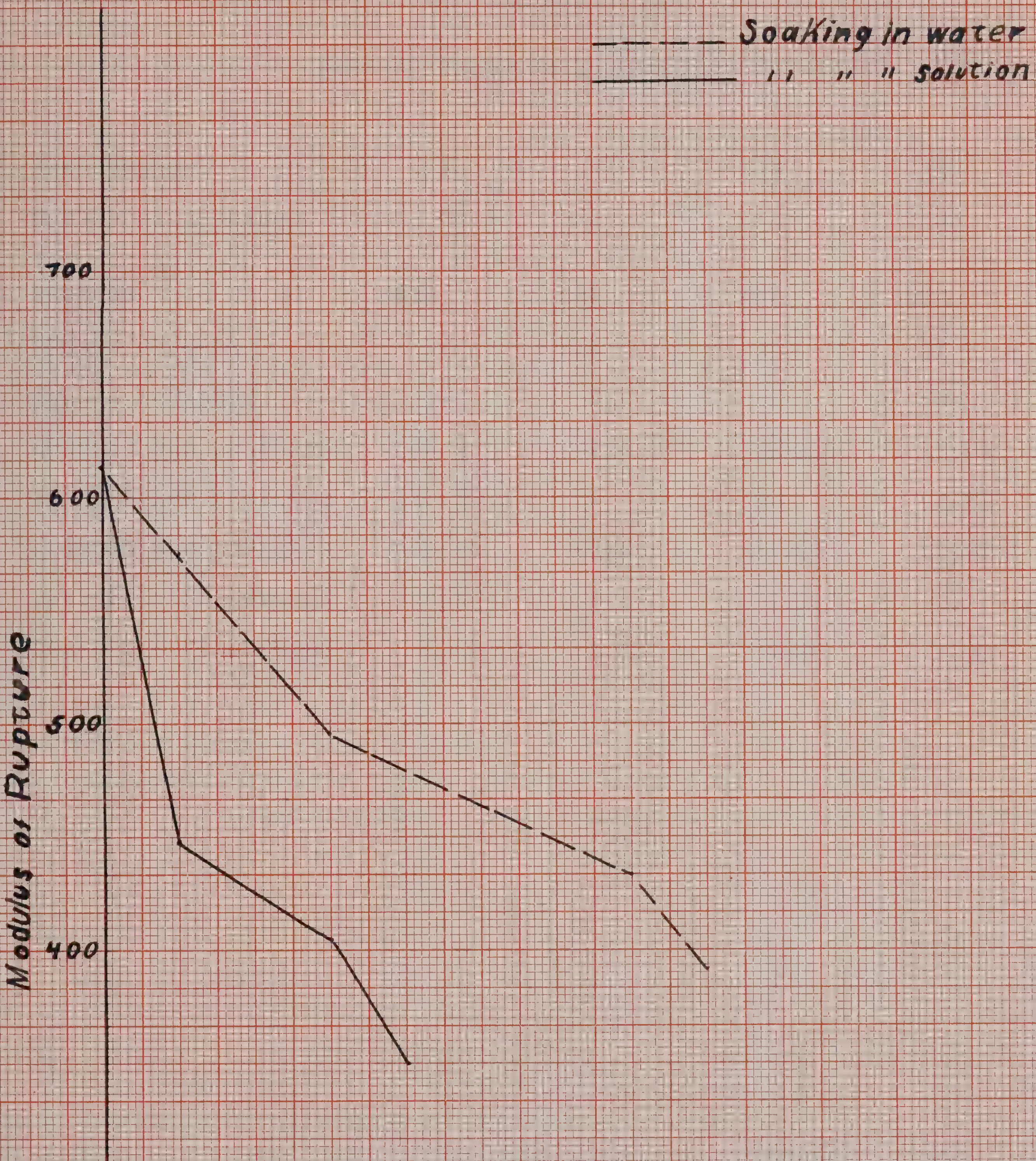
From the curve it can be seen that pottery plaster loses strength much more rapidly in the electrolyte solution than in water. This is due to the fact that the plaster is weakened not only by the effect of solution brought about by the water, but also by the reaction of the electrolyte with the plaster. Since the insoluble compounds, calcium carbonate and calcium silicate are formed by this reaction, the reaction goes to completion, making the attack severe.

C - Discussion of Results.

The fact that the electrolytes attack plaster has long been known to ceramists because of the scum of sodium sulfate brought to the surface of the mold by the water and left there upon its evaporation.

As further work along this line it would be well to attempt to find some cheap organic basic compound which would serve the purpose as an electrolyte and not attack the mold so rapidly as does sodium carbonate and silicate. The work should be done first to find several cheap electrolytes which may be used in the preparation of casting slips. Then it should be determined which one affects plaster the least. If one could be found which did not attack pottery plaster, the life of molds would be doubled.

Fig. No. IV



------ Soaking in water
—— " " " solution
Modulus of Rupture
700
600
500
400
300
0
1
2
3
4
5
6
7
8
9
10
11
12
Number of Three hour soaking periods

Data For Figure IV

Soaking Tests in Electrolyte Solution

Test Number	I	II	III	IV
Number of soakings	0	1	3	4
Average modulus of rupture	614	447	406	350
Number of bars	19	18	16	17
Number rejected	0	0	0	0
Average bar position	35.6	23.9	20.98	17.25
Maximum bar position	39.37	30	23	24.25
Minimum bar position	31.12	20.25	18.12	15.37
Deviation of maximum	3.77	6.1	2.02	7.
Deviation of minimum	4.48	3.65	2.86	1.88

Data for Figure IV

Soaking Tests in Water

Test number	I	II	III	IV	V
Number of soakings	0	1	3	7	8
Average modulus of rupture	614	574	496	434	390
Number of bars	19	15	17	16	16
Number rejected	0	0	1	1	3
Average bar position	35.6	33.1	27.4	23.1	20
Maximum bar position	39.37	42.25	33.75	31.87	28
Minimum bar position	31.12	25.5	18.5	15.12	14.25
Deviation of maximum	3.77	9.15	6.35	8.77	8
Deviation of minimum	4.48	7.6	9.9	8.98	5.75

IV

acknowledgement.

The writer wishes to express his
sincere appreciation to:
Mr. T. N. McVay for his valuable
assistance in formulating the
problem and his suggestions throughout
the work.
Professor R. K. [illegible] for his
many ~~criticisms~~ constructive
criticisms

VI- CONCLUSION

In conclusion it may be stated that:

(1) Pottery plaster should never be dried at a temperature above sixty-five degrees Centigrade.

(2) It should be kept moist in a damp closet for two days to allow time for complete hydration.

(3) As little of electrolytes as possible should be used in casting slips to minimize the effect on the molds.

(4) Plant operators and research ceramists should look for a cheap electrolyte which will not attack the molds and yet will serve the purpose.

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